THE INFLUENCE OF CLIMATE CHANGE ON SHORT-TERM FARM MANAGEMENT - AN INTERDISCIPLINARY MODELLING APPROACH

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Agriculture, especially plant production is directly affected by climate change as production processes are directly dependent on environmental conditions. Besides the long-term shifts in average temperatures and precipitation, the changes in the annual distribution of precipitation, temperatures and other climatic factors are likely to have implications for farm management in the future. Our idea is to increase the understanding of the short-term interaction between weather and agricultural management with an interdisciplinary modelling approach.

The model consists of two main parts that are interactively coupled: the economic and management part called FarmActor on the one side and the plant growth model (Expert-N) on the other. FarmActor contains several modules that determine the management decisions on the farm both for annual planning and daily actions. Here we focus on the parts covering the daily actions. The model FarmActor builds on the history of agent-based models and is designed to represent a single farm. It is a dynamic model in the sense that time is modelled explicitly on a daily basis and results of previous activities have consequences on later ones. This comprises expectations of future yields, the optimal timing of field management actions and soil conditions.

The model simulates the day-to-day farm management decisions. This comprises all management actions that are necessary to cultivate field crops, including soil preparation, seeding, fertilising and harvesting. The management actions are each driven by a set of conditions, (so-called “triggers”) all of which must be satisfied during one day for an action to be carried out (APFELBECK et al., 2008). Triggers implemented in the model include the stage of crop development, (maximum) soil moisture content, (minimum) air and soil temperature and, (maximum) daily precipitation pertaining to the day in question. Further, based on agronomic principals, the minimum average air temperature of several days before the potential day of action, and likewise the average soil temperature of 6 days serve as indicators of the consistency of environmental conditions. As a general planning parameter, a time-window stipulated by a minimum and maximum day of the year limits the execution of the action. At the end of these periods, the triggers e.g. soil moisture requirements are relaxed. If still the time window passes without successful completion of an action i.e. sowing or harvest, the model moves on to the next planned crop or activity.
For the example of winter wheat, the following actions and triggers are integrated: Sowing - day of year initially between 255 and 294 and consequently subject to modification, soil moisture max. 38 %, soil temperature min. 3 °C, no precipitation, soil has to be prepared already. Harvest - day of year between 180 and 273, crop stage at least 92, soil moisture max. 38 %, no precipitation, air temperature min. 8 °C.

The model is designed to simulate the effects of climate change on agricultural management decisions. Thus, the expected values of the main drivers of land-use and management decisions should not remain constant, but rather be modified gradually over the years. Thus a so-called learning module evaluates the results of previous crops before the new planning cycle starts. The expected yields are adapted according to observed yields in the past, the time window of sowing actions are adapted to observed weather. To adapt the sowing time window, for winter crops, remaining growing degree days are used. The beginning of the window is set to 4 days before the day at which the remaining growing degree days are expected to be 475 °C. The end of the period is then set to a date 42 days later. The subsequent actions other than sowing are mainly driven by the crop stage and daily weather conditions. Thus, their timing is adapted endogenously using the given triggers and modification of the time windows is not necessary.

As mentioned above, simulating crop management on a daily basis requires an approximation of crop development progress throughout the growing season. Thus we couple the economic part of the model to the crop growth model Expert-N (PRIESACK, 2006) which is an integrated, modular structured model of which we use CERES to simulate plant growth and DAISY to mimic soil nutrient dynamics. FarmActor and Expert-N exchange information on a daily basis. The management module of FarmActor accesses crop stage, soil moisture and soil temperature outputs from Expert-N and includes these data as detailed above. Upon execution of actions Expert-N is updated and restarts simulation of plant growth taking these actions into account.

The model has been calibrated to the agricultural situation in the Swabian Jura region of Baden-Württemberg (Germany). The triggers have been derived from crop management literature and expert knowledge and then calibrated to best reproduce the observed sowing and harvesting dates from the German Weather Service's phenological stations (DWD, 2012) and average district yields reported by the Statistical Office of Baden-Württemberg. The model can be driven both with measured weather data as was done during calibration (DWD, 2011) or with data from climate projections from models such as WETTREG (KREIENKAMP ET AL., 2010). First model runs show that it is capable to reproduce observed sowing and harvesting dates. Average sowing dates for winter wheat from 1980 to 2010 are reported at day 270 while FarmActor simulates sowing on average during the same period on day 267. Harvest date is reported on average on day 227, while simulated on average on day 222. Due to the inherent flexibility of winter wheat sowing date, we emphasised average planting day rather than correlation between simulated and observed dates. At the above averages, correlation coefficients between observed and simulated planting date was about zero, while for harvesting days it was at 0.63 respectively.
There is far greater difficulty in mimicking yields observed in the region. While the average yield of winter wheat in the Alb-Donau district was reported to be 66.95 dt/ha (1980-2010), simulated yields for the same periods are on average 75.34 dt/ha. However, when considering only the years 2001-2010 yields coincide well, (observed: 75.9 dt/ha; simulated 76.4 dt/ha). One reason for the deviation might be the change in cultivars and technology over the decades, which has yet to be captured in the model. Farmers’ decision making is likely to be more complex than simulated in the model. Still, simulations driven with future climate projections (WETTREG) show a shift towards later planting dates and earlier harvest dates. Yields tend to decrease while their volatility is increasing. Overall, the approach seems to be promising to deliver valuable insight into future German agricultural conditions under climate change.

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